

Multiple Sensors for Absolute Measurement of Aerobraking Spacecraft State Estimation

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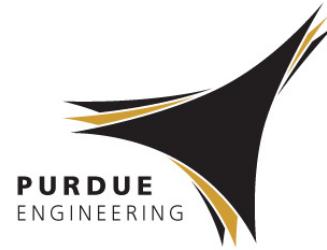
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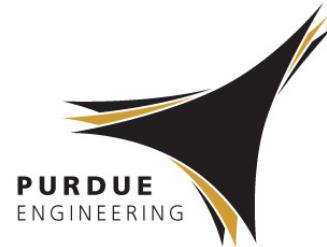
11th International Planetary Probe Workshop

Outline



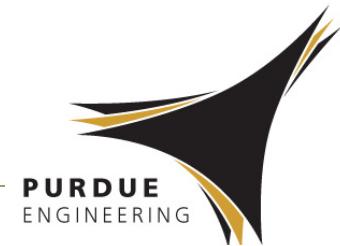
- Autonomous Systems Lab (ASL): goal & context
- Aerobraking (AB) context
- Previous aerobraking state estimation
- New state estimation strategy
- Advantages of our method
- Conclusion & future work

ASL goal & context

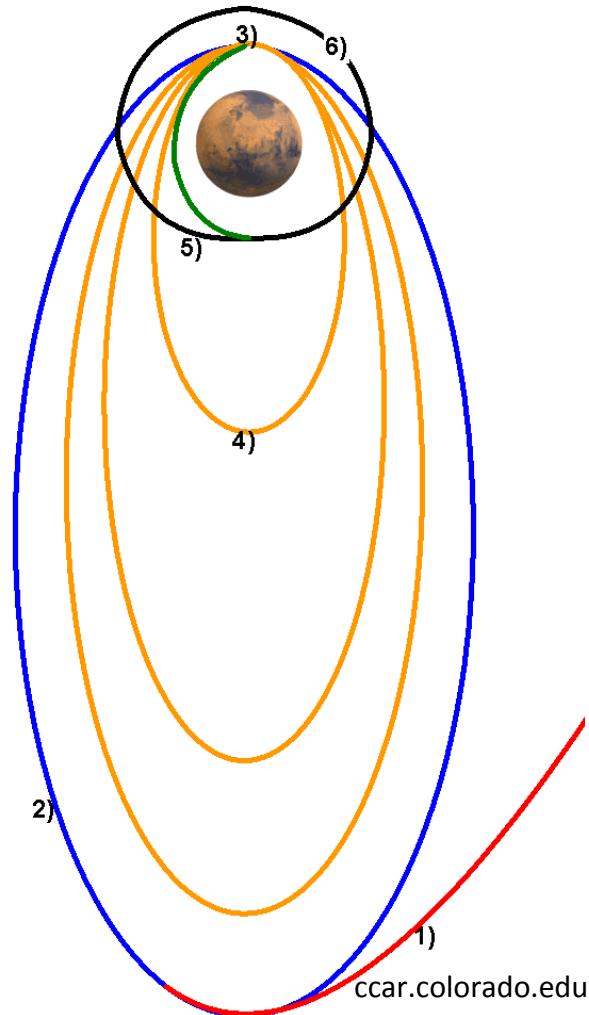


- Development of multiple sensors strategy
 - Improve spacecraft state estimation
 - Reduce estimation error by combination of direct measurements
 - Relative vs absolute measurements
 - Increase spacecraft autonomy
 - Reduce cost
 - Reduce operational cost
 - Reduce cost by using low SWaP (size, weight and power) sensors

Aerobraking (AB) context

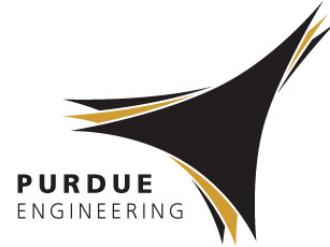


1. Initial orbit insertion
2. High elliptic orbit
3. Spacecraft flies through upper atmosphere near perigee
 - Drag force reduces spacecraft velocity
 - Apogee altitude is reduced after atmospheric pass
 - Multiple passes
4. Apogee burns to control perigee
5. Perigee raising burns to go to final orbit
6. Final orbit



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Aerobraking (AB) context



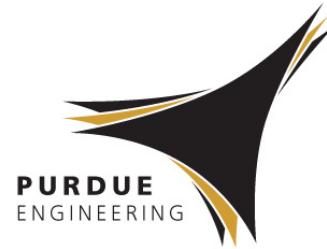
- Control corridor
 - Upper boundary constraint: maximum temperature
 - Lower boundary constraint: maximum aerobraking duration
- Control variables
 - Peak dynamic pressure
 - Peak heat flux
 - Heat load per pass

$$p_{dyn_peak} = \max\left(\frac{1}{2} \cdot \rho \cdot V_{atm}^2\right)_{drag_pass}$$

$$\Phi_{peak} = \max\left(\frac{1}{2} \cdot \rho \cdot V_{atm}^3\right)_{drag_pass}$$

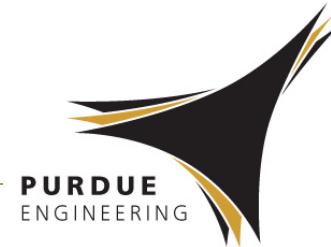
$$\Delta Q = \int_{drag_pass} \Phi(t) dt$$

Traditional AB state estimation



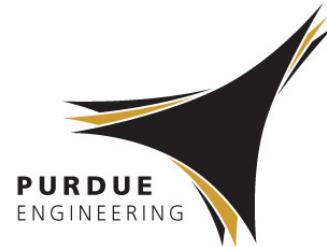
- Radiometric tracking data
 - Processing post-atmospheric-pass data
 - Time and cost consuming:
 - orbit reconstruction
 - Aerobraking events generated by ground personnel
 - Possible aerobraking corridor control maneuver errors due to time delay and post-atmospheric-pass state uncertainty
 - Can lead to inefficient propellant usage
- IMU as orbit determination measurements
 - Limited post-drag-pass data process
 - Provides state estimation and reconstructed atmospheric profiles
 - Cons: highly dependent on initial state and error propagation

New state estimation strategy



- Multiple distributed sensors
 - Low SWaP sensors
 - Large distribution
- Inertial vs absolute measurement
 - IMU (accelerometers, gyroscopes...)
 - Star tracker (CCD, CMOS imagers, fisheye lens...)
- Rigid vs flexible body
 - Sensors distribution

State estimation strategy



- Mathematical model
 - Accelerometer

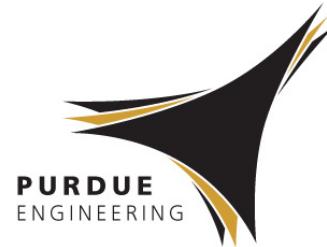
$$\frac{d^2 r}{dt^2} = \frac{d^2 R}{dt^2} + \frac{d^2 r'}{dt^2} \omega \times \omega \times r' + 2\omega \times \frac{dr'}{dt} + \alpha \times r'$$

- Star tracker

$$\xi_i = -f \frac{A_{11}(X_i - x) + A_{12}(Y_i - y) + A_{13}(Z_i - z)}{A_{31}(X_i - x) + A_{32}(Y_i - y) + A_{33}(Z_i - z)}$$

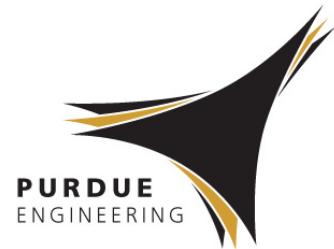
$$\chi_i = -f \frac{A_{21}(X_i - x) + A_{22}(Y_i - y) + A_{23}(Z_i - z)}{A_{31}(X_i - x) + A_{32}(Y_i - y) + A_{33}(Z_i - z)}$$

Advantages for AB



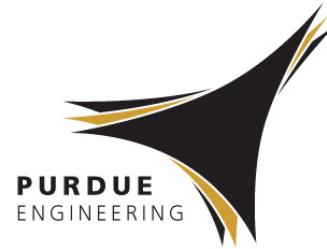
- Cost reduction due to limited post-drag-pass operations
- Reduction of error propagation
- Enable new control strategies for:
 - ABM at apogee (perigee control)
 - Autonomous control during drag-pass (real-time corridor control)
- Validate and improve atmospheric models (determination of density)

Summary



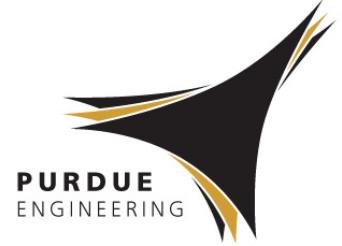
- Multiple distributed sensors and absolute measurement
- Autonomous state estimation
- Cost reduction (operational cost, low SWaP sensors)
- Better control strategy, lower risks

Future work



- Develop real-time corridor control strategies
- Simulate and validate our method within other simulation tools
- Hardware sensors testing
- Apply our state estimation method to other autonomous situations

Thank you!



Questions ?



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